ON THE MAKING OF ELECTRET AND MEASUREMENT OF THE CHANGES OF DIELECTRIC CONSTANT OF A POLARISED ELECTRET FORMING MATERIAL WITH TIME*

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ABSTRACT. Electrets were made with commerically available carnauba wax.

Influences of voltage and temperature on the formation of electrets were studied.

Attempts were made to measure the surface charges with an electrometer.

Variation of dielectric constant ε and tan δ were measured with time by means of a universal capacity bridge.

On application of the field in the molten condition of the material, only a fraction of the dipoles orient in the direction of the field, larger portion orient randomly in all other possible directions. Alignments of the dipoles in the parallel direction increases the dielectric constant. Depending on time more of the dipoles orient in the parallel direction due to the field induced by the dipoles, thereby increasing the value of dielectric constant In the present investigation, abnormally high increase in the value of dielectric constant along the direction of the field was obtained. But when the dielectric constant was measured at right angles to the direction of the field, the values of the treated material were found to be lower than those for the control sample.

A. C. conductivity of the material was calculatded from the measured values of ε and tan δ.

1. INTRODUCTION

Adams (1927) found that electret materials were piezo-electric. But Gemant (1935) and Nakata (1927) could not find any piezo-electric effects, and Thiessen (1936) and co-workers obtained only small deflections of the electrometer upon the application of pressure, which they ascribed to capacity changes rather than to piezo-electricity. In view of this apparent contradiction, it was thought worthwhile to undertake further investigations to elucidate the question.

The experimental investigation here reported was undertaken with the hope of finding out some materials which on being electrically conditioned, might attain piezo-electric property. An artificially made piezo-electric material may be

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fruitfully utilized to the best advantage as a substitute for piezo-electric quartz crystal and also magnetostriction type transducer to generate ultrasonic energy in a certain frequency range—specially in the lower frequency region 20-100 kc/s. Intensive private commercial investigations have been made. But their findings are of no use to the scientific investigators as they are naturally unwilling to disclose their findings.

Materials having permanent dipole moment may attain the property of piezo-electricity, when they are electrically treated. Under this condition, they may be said to have attained the property known as electro-strition. Likewise, in the field of magnetism, there is magneto-striction. By electro-striction it is understood that the volume of the dielectric material changes, resulting from electric polarisation. Of considerably greater interest is the production of permanent polarity in a dielectric whereby a polarised baror plate of dielectric behaves like a permanently polarised steel bar or plate; such an object was called by Heaviside (Engineering, 1885, quoted from Physical Chemistry by Partington, J R.) an 'electret'. Usually the properties of the polarised material measured do not include that of elctro-striction but includes the measures of ϵ and tan δ.

When an electric field is applied to a polarised material along the direction of the permanent polarisation, the material lengthens. If the applied field is reversed, a shortening occurs. Thus an alternating field applied along the same line as the polarisation causes the material to alternately lengthen and shorten its dimension along this line. This effect is used directly in driving thickness vibrations in the direction of the applied field. It is used indirectly through Poisson-effect in driving radial vibrations of a disc, and length vibrations of a bar when field is perpendicular to length. By applying the driving field perpendicular to the direction of permanent polarisation a shear strain is produced.

Electrets were investigated experimentally by a number of workers (see references). A mixture of wax, specially carnauba wax, a little beeswax and rosin are used and the fused mixture is allowed to solidify in a strong electric field. It has been found that the charge so produced on the surface is not removed by a flame, treatment with X-rays, washing with various liquids or shaving off the surface with a knife. When the charge on the surface is removed it re-appears after a time. The surface charge is measured by an electrometer. The initial surface charge is a hetero-charge, opposite in sign to the charge on the metal plate during the preparation, but there is a rapid change to a homocharge, of the same as that on the plate. The anode layer assumes a short-lived positive charge, rapidly subsiding to a steady somewhat lower positive charge which is constant for several days. The general conclusion is reached that the charge on an electret is not due to polarisation of the dielectric throughout the mass, but is in the nature of a surge charge communicated from the electrodes.

In the present investigation, initially, an attempt was made to measure the surface charge against time by means of a Wulf's type electrometer. But no satisfactory results were obtained. The electret was found to behave like an electrophorous and so measurements with this electrometer was discontinued. Subsequently measurements were made of the change of dielectric constant of the electret forming material with time, after it had been treated with unidirectional electric field. The property of the polarised material includes the measure of c and tan δ.

In course of the measurements of the dielectric constant ϵ and tan δ some remarkable findings were obtained. It was found that the dielectric constant increased to an abnormally high value after some days. This high value after hovering for some days dropped down to a lower value. In the present report, the changes of dielectric constant with time under different conditions of the formation of electrets, are presented. The piezo-electric effects of electret will be reported later on. The results obtained are shown in the diagrams (figures 2–6).

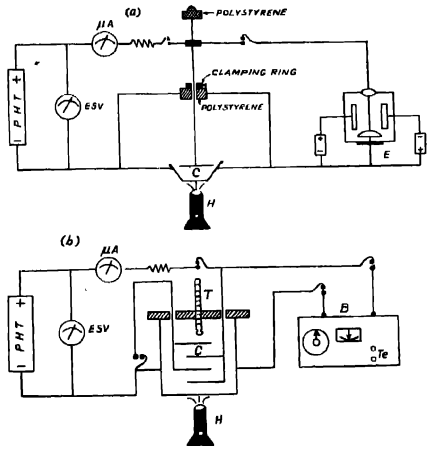

Fig. 1.—The schematic experimental arrangements for making an electret and devices to measure charge, dielectric constant ϵ and tan δ.

P.H.T.—Polarising High Tension ESV–Electrostatic voltmeter; μA–Microammeter; C–Capacitor unit which contains the dielectric under investigation; E–Electrometer; B–Universal capacity bridge; T–Thermometer; Te–Headphone; H–Bunsen burner.

2. THEORETICAL CONSIDERATIONS

Molecules are composed of positively and negatively charged particles in such numbers that they are neutral as a whole. In polar molecules there is finite distance of separation between what may be termed the centres of gravity of posi-

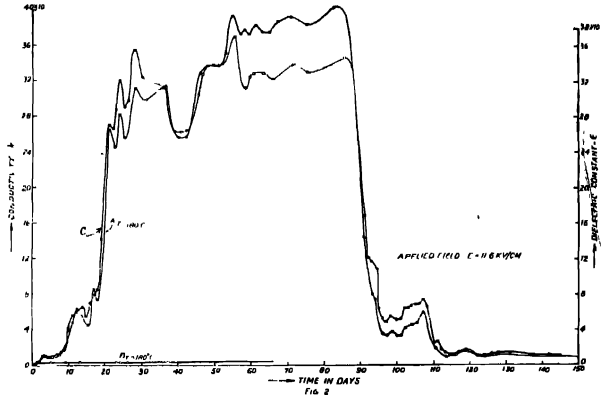

Fig. 2

Fig. 2. Graph A shows the plot for the change of dielectric constant of the specimen under test against time in days. A_T180°C–Temperature, when the field was applied. Graph B shows the plot for the change of dielectric constant of the control specimen against time B_T180°Crefers to temperature up to which it was raised. Polarising field E = 11.6 Kv/cm. Graph 2C–shows the change of a.c. conductivity R of the polarised material against time.

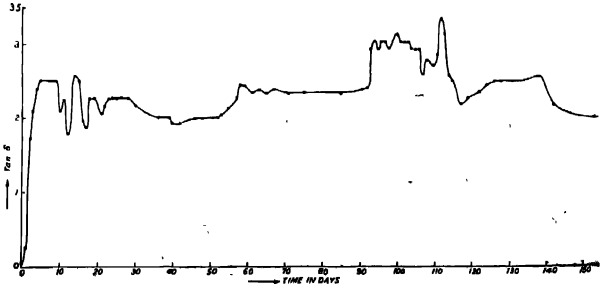

Fig. 3. The change of tanδ against time

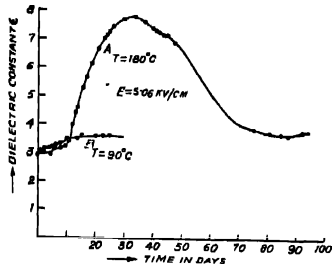

Fig. 4. Graphs A $_T$180°C and B $_T$90°C show the effect of temperature of the material at which the field was applied on the change of dielectric constant with time.

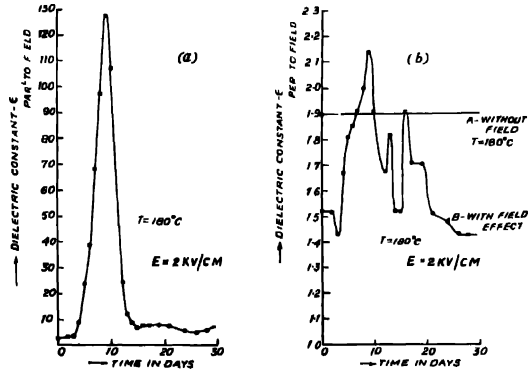

Fig. 5. The change of dielectric constant against time. Fig (5a)—Along the direction of field; Fig. (5b), Curve B–change at right angles to the direction of field and curve A–shows the change for the control specimen in the capcitor placed perpendicular to the field.

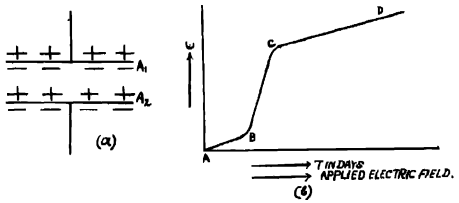

Fig. 6.

tive and negative electricity, and the polarity of a molecule becomes less as these centres of gravity in a molecule approach each other. When placed in an electrical field a polar molecule will tend to orient itself in such a way that the positive part of the molecule points towards the negative electrodes and the negative part points to the positive electrodes. The force required to orient the molecules will depend on the magnitude of the charges and on the distance between them. The dipole moment is defined as the product of one of the charges and the distance between the two average centres of positive and negative electricity.

On application of external electric field, the dipoles of the domain structure orient in the direction of the applied field. It is assumed that orientations of molecules in all directions are equally probable. The alignments may be in parallel, antiparallel and other directions. Under the aligned condition, the medium is said to be polarised. Saturation electric polarisation, apparently, cannot be reached without dielectric breakdown. For this breakdown of the dielectric medium an electric field of the order 10^8V/cm is required. From the practical point of view, it is too difficult a situation to be materialised easily. But in the neighbourhood of an ion, or the dipole, the field may be as high as 10^8V/cm. There is also a dependence of dielectric constant on the applied field and electrostriction.

On account of the regular distribution, the dipoles are mutually coupled in a special way by the very powerful internal field in the structure. If a weak field is applied, the internal field enhances it by resulting orientation of the dipoles. The spontaneous parallel arrangement of all dipoles gives rise to a high dielectric constant, but also occasions a very large dielectric loss due to hysteresis. The oriented dipoles exert supplementary forces and the resulting change of dimensions leads to new positions of stability.

Solid substances, such as Rochelle salt, ammonium dihydrogen phosphates and barium titanate have got unusually high permeabilities (or dielectric constants). These are the analogues in electrical properties of the so-called ferromagnetic bodies with abnormally high magnetic permeabilities and also showing the properties of hysteresis and permanent magnetism. The correspoding dielectrics, in view of their essential property, the unusually high dielectric constant, are termed as hyperelectrics. Many of the fundamental ideas have been carried over to the electrical analogues, in particular that of domain structure. While considering the domain structure, the elementary dipoles are identified with domains containing a large number of atoms, the permanent dipole moment of which are aligned in one direction inside each domain. This alignment is assumed to be due to a permanent intra-molecular field extending over the whole volume of the domain, the existence of the field is supposed to characterise a hyperelectric material. Many investigations have been carried on Rochelle salt, AD phosphates and barium titanate. But no investigation has yet been

carried along these lines on carnauba wax. In the present investigation, an attempt was made to investigate the case of carnauba wax.

(a) *Calculation of polarisability*

Let the material under investigation contain N_1 molecules per cubic centimetre, all of the same kind and in the same state a. The polarisation of the medium will be

(1) $P = N_1 R$, where R stands for dipole moment.

For an isotropic medium, the Lorentz field,

(2) $E^1 = E + 4\pi P/3$ may be denoted as the effective field. Expressing E^1 by this relation, the expression for the polarisation of the medium may be written as

(3) $P = N_1 E/\left(\frac{1-4\alpha N_1\pi}{3}\right)$ where α stands for the polarisability of the molecule in the state a.

From electromagnetic theory, the electric displacement vector D may be expressed in the following way,

(4) $D = \epsilon E = E + 4\pi P$, where ϵ is the dielectric constant of the medium.

In terms of polarisability, the dielectric constant may be written as

$$(5) \qquad \epsilon = 1 + \frac{4\pi N_1\alpha}{1-4\pi N_1\alpha/3} \quad \text{or} \quad \frac{\epsilon-1}{\epsilon+1} = \frac{4\pi N_1\alpha}{3}$$

With the help of the equation (5), the amount of polarisation produced in the electrically polarised dielectric material can be estimated. This partial polarisation is supposed to be responsible for the piezo-electric effect.

(b) *Calculation of a.c. conductivity of the dielectric material*

An alternating field,

(6) $E = E_0 \sin(2\pi t/T)$, where T is the period, when it acts on a dielectric, the current through the dielectric is represented by

(7) $I(t) = I_0 \cos(2\pi t/T - \delta) = I_0 \cos\delta \cos(2\pi t/T) + I_0 \sin\delta. \sin 2\pi t/T.$

The cosine term represents the displacement current and the sine term, the conduction current. If C is the capacity

(8) $I_o \cos\delta = (2\pi/T)\, C.\ E_0;\ I_0 \sin\delta = (4\pi R/\epsilon)\ CE_0$, where R is the conductivity and ϵ is the dielectric constant. The loss angle δ is determined from equation (8) by

(9) $\tan\delta = 2TR/E$

Or $\qquad R = \epsilon \tan\delta/2T$

3. EXPERIMENTAL ARRANGEMENTS

The entire experimental arrangements are shown in the schematic diagrams figures 1(a) and 1(b).

Figures 1(a) and 1(b) show the arrangements of melting, polarising by applying external fields, and the respective apparatus for measuring charges, dielectric constant ϵ and tan δ. Temperature was recorded by means of the thermometer T. In figure 1(a), the electrodes dipped into the molten dielectric were of tin and those in the figure 1(b) were the commercially available condenser plates. The external field applied to polarise the material was measured by means of an electrostatic voltmeter and the current through the material during the time of polarising was observed by means of a microammeter, connected as shown in the figures 1(a) and 1(b). These meters remained connected till the material was cooled down in air.

Carnauba wax, the material under investigation in the present experiment, was melted and the temperature was raised to some higher level above the melting point. At a particular temperature (kept approximately constant by manual manipulation of the flame) the external field was applied, and the material was kept under tension of this applied field at that temperature for about 15 minutes. Then the flame was removed and allowed to cool in air. It required about 8 to 10 hours to solidify. (This was verified by actual experiment). After solidification the external field was removed and the charge was measured by a Wulf's type electrometer, and the dielectric constant ϵ and tan δ were measured by means of a universal capacity bridge. From the magnitudes of the measures of charges or change of dielectric constant the amount of polarisation produced in the material were estimated and thereby confirming whether the specimens of material under investigation were turned into an electret or not. Electrets were made under the following conditions :

S. No.	Temperature in 0°C	Applied field KV/cm
(1)	90	5.1
2(a)	180	2.0
(b)	180	5.1
(3)	180	11.6

(4) Two condenser units arranged in such a way so that the plates of one unit is orthogonal to the other unit.

This is to measure dielectric constant both par^l to the direction of the applied field and perp. to the direction of the applied field.

(5) Material was melted and temperature was raised to 180°C and then allowed to cool in air. In this case no external field was applied. This specimen served as a control.

4. MEASURING INSTRUMENTS

1. Wulf's single string electrometer

A schematic diagram of the electrometer is shown in figure 1. The fibre is placed in a uniform electric field between two knife edges. The lower end of the fibre rests on a quartz bow and the upper end being connected to an electrode which passes through a high grade insulator. The arrangement of connecting the specimen under investigation and the electrometer is shown in figure 1. The fibre deflection is observed on a micro-scale fitted in the eye-piece of a telescope. The capacity of the system being previously determined, the charge stored by the electrometer can be ascertained.

2. *Marconi universal capacity bridge Type No. TF* 868/1. This instrument incorporates an oscillator to generate a.c. voltage of 1000 c.p.s. There is an a.c. bridge circuit arrangement in which the oscillator output voltage of definite magnitude is applied. Any change in the capacity of a condenser is observed from the deflection of the meter. Direct readings of capacity are obtained in this apparatus. There is also provision to measure tan δ, where δ is the loss angle and Q which is reciprocal of tan δ. Another provision is included to insert a headphone. The readings of the capacity of a condenser are taken from the graduated dial corresponding to the null-deflection of the indicating meter or from the minimum intensity of sound produced in the head-phone. Both these devices may be employed simultaneously quite independent of each other to determine the capacity of a condenser so as to ensure more correct readings.

5. EXPERIMENTAL

(a) In the first part of the present investigation, attempts were made to measure charges in the electrically treated dielectric material by means of an electrometer against time.

The hypothesis behind this measurement was that the molecules having dipole moments would align in the direction of the applied d.c. polarising field --field being applied in the molten condition of the dielectric material and continued so till the dielectric was solidified. So the surface near the positive electrode would be negative and that near the negative electrode positive. This dielectric system would then act as an electrostatic cell having two distinct positive and negative poles at the two faces but possessing no current supplying capacity, unlike the storage cell which can supply current. When such a cell is connected across a sensitive electrometer, there should be some deflection of the fibre of the electrometer, thereby proving the development of voltage due to charge formation at the surfaces. But when the experiment was performed, no deflection of the fibre was obtained even at the most sensitive condition of the electrometer.

In the next phase, this cell system being connected to the electrometer, the upper electrode was raised suddenly by holding the rod attached to the electrode by means of a polystyrene insulator (shown in the diagram figure 1a). This time the electrometer fibre was deflected and the deflection was also obtained when the electrode was suddenly brought near the surface of the dielectric but not physically touching it. This kind of operations of the electrode gave deflections of the fibre even when the two faces of the dielectric were earthed before each operation. The explanation of these observations will be given in the next section.

The experiment was not continued any more, as no convincing and consistant results were obtained with the electrometer which was supposed to be not sensitive enough for these measurements.

(b) Finding no promising results in the charge-measurement experiment, the direction of experiment on polarised dielectric material was turned to a different course. This time attempt was made to measure the change of dielectric constant ϵ and tan δ with time so as to obtain information of the amount of polarisation produced in the dielectric.

In connection with the measurements of dielectric constant ϵ and tan δ, the following experiments were performed with the help of the universal capacity bridge as described in the previous section :

(1) To measure the change with time the dielectric constant of a given wax material which was melted and subsequently allowed to solidify in a given electric field (figure 2*a*).

(2) To measure the variation of tan δ with time of the same specimen (figure 3).

(3) To study the effect of the strength of the initial polarising field on the subsequent change in the dielectric constant of the material with time (figures 2*a*, 4*a*).

(4) To study the effect of the temperature of the molten dielectric at the time of applying the polarising field, on the subsequent change with time of the dielectric constant of the material (figure 4).

(5) To measure the changes with time of the dielectric constants, both in the direction of the applied field and perpendicular to the direction of the applied field (figures 5*a*, 5*b*).

(6) To study the effect of melting the dielectric without any impressed field on the subsequent change of dielectric constant with time (figure 2*b*).

Experiment No. 6 served the purpose of a control.

6. RESULTS AND DISCUSSION

(a) The observations that were made in the measurement of charges were not consistent and conclusive, and so the results obtained have not been reported

in the present paper. A remarkable observation was however made viz., the fibre of the electrometer deflected when the upper electrode was suddenly raised from or brought near the surface. This finding can be explained only if the dielectric with the two electodes system is assumed to act as an electrophorous. The dielectric became polarised while an external electric field was applied in the molten condition of the dielectric. Subsequently, it was cooled in air without the applied voltage being withdrawn. No discharge could develop at that state. On the two opposite surfaces of the dielectric slab positive and negative free charges accumulate due to the applied field. This can be neutralised by a leak discharge through the body of the dielectric slab. In our case the leak discharge was extremely small and not detectable with the instrument used and the charge remained frozen-in.

Dielectric absorption observed in all solid dielectrics, is caused by delayed orientation of dipoles, molecular rearrangements, displacements of strain of covalent bond and ionic displacement in polarisation. On account of absorption,

TABLE I

Expt. No.	Value of air capacitor	Polarising field EKV/cm.	Temperature of the dielectric when the field was applied	Freq. of the measuring voltage	Results of experiment as obtained against time
1	2	3	4	5	6
1	33.5 $\mu\mu$f	11 6 Kv/cm	180°C	1000 c.p.s.	Fig. 2*a*
2	33 5 $\mu\mu$f	11.6 Kv/cm	180°C	1000 cp..s.	Fig. 3
3	33.5 $\mu\mu$f	11.6 Kv/cm	180°C	1000 c.p.s.	Fig. 2*a*
	28.5 $\mu\mu$f	5.06 Kv/cm	180°C	1000 c.p.s.	Fig. 4*a*
4	28.5 $\mu\mu$f	5.06 Kv/cm	180°C	1000 c.p.s.	Fig. 4*a*
	28.5 $\mu\mu$f	5.06 Kv/cm	90°C	1000 c.p.s.	Fig. 4*b*
5	2.1 $\mu\mu$f		180°C		Fig. 5b
	Perp. to Fiel				
	10.2 $\mu\mu$f	2 Kv/cm		1000 c.p.s.	
	Par^{l}. to Field		180°C		Fig. 5a
6	33.5 $\mu\mu$f	No field	180°C	10000 c.p.s.	Fig. 2B

[Table I shows the conditions under which the experiments were carried out Column (6) refers to the figures where the respective values of ε and tan δ are plotted against time. Column (3) shows the value of applied polarising field and column (4) the temperature when field was applied. Last row shows the experimental characteristic of the control specimen].

a capacitor containing solid dielectric can neither be charged nor discharged instantaneously. Dielectric absorption in combination with an adequate heat treatment produces the electret effect.

Further work in this line, with a much more sensitive electometer, is in progress.

(b) Experimental results of the dielectric constant ϵ and tan δ measurements of a typical sample of commercially available carnauba wax, are shown in the figures (2) to (5), and table I shows The different conditions of experiments in a summarised way.

In the present investigation, no attempt was made at securing high precision. Here the main object was to get information of the change of polarisation due to the action of electric field, in a very qualitative way. This in turn was obtained from the measurements of the dielectric constant. To that extent, the present investigation is a successful one. Not only dielectric constant ϵ but also tan δ, was measured in the same experiment. Knowing ϵ, tan δ and the period T of the a.c. measuring voltage, the conductivity was calculated by utilising the formula (9).

The results of the experiments performed are shown in the figures (2), (3), (4) and (5). The figure 2(C) shows the calculated a.c. conductivity of the polarised material against time.

I. (A). Figure 2, graph 2A shows the variation of dielectric constant ϵ against time. From the study of the graph 2A, it is evident that there is a gradual rise of the dielectric constant for the first 13 days. Then after the 18th day there is a sharp rise in the measure of ϵ. The value of the dielectric constant remains at that higher level—with many ups and downs—for about 68 days and after which there is a sharp fall . On close observation of the curve, it is found that the fluctuations in the measurements of the dielectric constant before the date of sharp rise have got some correspondence with the same after the date of fall. Moreover, in the measurements of the dielectric constant at the higher level state, it was noticed subjectively that the head-phone gave indications of tremendous noise and it was very difficult, sometimes it was practically impossible, to get the minimum sound-position at the highest sensitive condition of the measuring instrument. This excess noise may be attributed to be the cause of molecular re-arrangements due to internal induced field. Greater the number of dipoles aligned in the direction of the field, greater is the polarisation. Here it may be supposed that on the application of the field in the molten condition of the material some dipoles were aligned in parallel and some in antiparallel and the rest in all other directions according to the following statistical law, $n = n_0 e^{-\mu F/KT \cos\theta}$. where T is the temperature of the substance.

(B) *Interpretation of the mechanisms involved in the entire process of making*

The wax material is kept for a few hours in molten condition in a strong electric field and then allowed to solidify with the field on, after which the external electric field is withdrawn.

We may picture the solidified wax material as follows:

(I) At the two ends are two strongly polarized electrets A_1 and A_2 in figure 6(a)

In between these two electrets are the wax dipole molecules, which try to orient themselves parallel to the direction of the field due to the two electrets A_1 and A_2. Such orientation are opposed by the viscous forces in the material of the wax. Gradually there will be increasing alignment of the wax molecules along the directions of the field due to A_1 A_2. The measure of this orientation will be the change in the value of dielectric co-efficient.

The variation of the predicted change of ϵ with T as illustrated in figure 6(b) corresponds roughly with the observed dependence of ϵ with T as given in figure 2(*a*).

(i) In first stage the portion AB of figure 6(b) represents an almost linear increase of dielectric coefficient with the applied finite A.C. field. This corresponds to the portion of the curve in 2(A) between 0 and 15 days.

(ii) in the second stage BC of figure 6(b) when the dielectric co-efficient increases very rapidly with the applied A.C. field corresponds to the portion of curve 2A between 15 and say, 22 days.

(iii) we can consider that corresponding to the portion CD of figure 6(b) is the portion between 22 and 90 days in the curve 2A.

(iv) there is an abrupt change in the dielectric coefficient curve 2A between 90 and 110 days. Probably more than one interpretation of this observed effect is possible. The following one appears to be reasonable.

During the stages (i) to (iii) the field due to the electret pair can be assumed to remain on the whole constant. Even during this period there is gradual loss of charges forming the electrets pair A_1 and A_2 due to

(a) loss of charge to the surrounding air and (b) due to conduction through the main body of the slightly leaking dielectric. When the charges on A_1 and A_2 become negligible, we arrive at a stage when there is a dielectric polarisation in a viscous dielectric body not maintained by any external electric field. The tendency towards random orientation of the dipole molecules in a zero external field which corresponds to an increase of entropy becomes effective and the wax body returns to its initial state.

(C) *Quantum-mechanical picture.*

In the language of quantum mechanics, it may be said that the molecules had moved to the state b from the state a. The state b represents a state for higher dielectric constant than that for states a. State of interchange of molecules were caused partially by the applied electrical field and subsequently the stage b was attained by the time dependent induction of field due to dipoles. The state b of the system of molecules is the unstable state. So the system returns to the stable state a after a length of time. The life of the state b depends upon the applied electric field. This is evident from the graphs 2A and 5A, as obtained in the present investigations. The entropy of the molecular system in the state b decreased as the system passed from the state a, where the entropy of the system was larger, to the state b. As the transport was forced, the systems reverted to the stable state a when the influence due to the applied field died down. This suggests the breakdown of the alignments of the domains.

2. Further it was found that the abnormally high value of the dielectric constant of the polarised material, came down to the normal value when the material was remelted. Melting of the material destroyed the aligned distribution of the dipoles and so there was no evidence of the increase in the value of the dielectric constant with time.

3. Tan δ which determines the loss, was measured with the capacity bridge. The plot of tan δ against time is shown in figure (3). From the graph, it is clear that the value of tan δ was very small at the start. But in five days, the values increased very rapidly. Subsequently it remained at the higher-value level having some fluctuations. From a comparative study of the curves for (i) dielectric constant ϵ against time (figure 2, curve A) and (ii) tan δ against time (figure 3), it is found that the value of dielectric constant dropped down to a lower level after about 90 days and thereafter gradually attained the values of ϵ nearing those of unpolarised material but the values of tan δ did not drop down to lower level. The cause for the attainment of lower values of ϵ may be attributed to the breakdown of the alignment of the domains. That for the higher values of tan δ even when the values of ϵ came down to lower values, may be interpreted in the following way. Values of tan δ depend on the product of the dielectric constant and the resistance which is a hypothetical series or shunt resistance associated with the actual condenser to account for the loss in the dielectric. Since the mean values of tan δ as obtained in the present investigation are found constant, it may be inferred here that this constancy i.e. the product $\epsilon \times R$, can be maintained even when the value of ϵ dropped down to lower level, if there is a corresponding rise in the values of R. An increase in the value of κ is possible, if the alignments of the domains break down. In the present investigation, the results indicate that this state of affair might have occurred. These two observations on dielectric

constant and tan δ suggest that the alignments of the domains broke down after about 90 days and the material lost its electret property.

4. The a.c. conductivity of the material was calculated with the help of the equation (9). Calculation of κ required the measured values of ϵ and tan δ of the material and also T, the period of the measuring voltage. The plot κ against time is shown in the graph figure 2(C). Greater the development of surface charges, greater will be the a.c. conductivity. In the present investigation, the cause of the variation of a.c. conductivity of the material against time, may be attributed to the alignments of more and more dipoles in the direction of applied field, resulting thereby in greater amount of polarisation and hence surface charges which caused the increased value of a.c. conductivity.

5. The temperature of the molten material, at which the field is to be applied plays an important role in making electrets. Results of typical experiments performed, are shown in the graphs 4A and 4B. Here the applied voltage remained the same, but in one case the temperature was 180°C and in other 90°C. For this particular sample of the material, a compromising temperature of 180°C was found suitable for better results, without destroying the property of the material. Above 220°C, the material got charred. Considering these points, all the experiements were performed at 180°C.

6. In an experiment, the change of dielectric constants both in the direction of the applied field as well as at right angles to the field were measured. Results obtained are shown in graphs 5(a), 5(b) A and B. Figure 5(a) shows the change of dielectric constant along the direction of the field. Graph A of figure 5(b) shows the change of dielectric constant against time, when the system acted as a control and graph B of the same figure shows the variation at right angles to the applied field. Here it is apparent from the graphs A and B that the dielectric constant decreased with time, with the exception for a short period of 3 to 4 days, when the value of the dielectric constant was larger than the control. In all the experiments, where the dielectric constants were measured along the direction of the field, the values were always higher than those of the control from the very start of the experiment. This remarkable observation of the present investigation may be interpreted in the following way.

The domain structure may be supposed to have three axes of symmetry. Of the axes (X, Y, Z) say, the X axis was aligned in the direction of the field and the other two Y and Z at right angles to X, were oriented in any other direction. Under the joint action of the field induced by the dipoles and the measuring voltage one of the axes Y or Z was oriented in the direction at right angles to the field. So the dielectric constant increased. The curves are drawn in a magnified scale so as to show the small changes in the values of dielectric constant clearly.

7. The effects of the applied field on the making of electrets are shown in figures 2 and 4A. Larger the magnitude of the applied field, more enhanced

is the effect produced. Moreover, the life of the state *b* depends on the applied field. Results of the experiments as depicted in figures 2 and 4A support this view. Exact relationship between the applied field and the life of the state *b* of the electrically treated material cannot be decided at this early stage of experiments. For this, experiments in details are being undertaken.

The present investigations being preliminary, no attempt to theorise or go into the details of the experimental studies was made. Here the main object was to make an electret and then to employ it to generate ultrasonic energy. The preliminary observations on the first part are reported here. Works with greater details are in progress.

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